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Lead Time Optimization of W32 Connecting Rod Lower Part in Robot Cell

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Tämän opinnäytetyö tehtiin Wärtsilän kiertokankiverstaalle. Opinnäytetyön tarkoituksena oli nopeuttaa W32-kiertokangen alaosan läpimenoaikaa robottisolussa.

Kiertokankiverstas muutti tuotantoprosessiaan helmikuussa 2016. Entisen manuaalisen prosessin tilalle tuli lähes täysin automatisoitu solu. Tarve tälle opinnäytetyölle syntyi, kun robottisolun huomattiin olevan hitaampi kuin odotettiin ja viimeistelyä ei ollut tehty.

Työ toteutettiin käymällä automaattinen prosessi kohta kohdalta läpi, ja muuttamalla turhan hitaat nopeudet ja mukauttamalla liikepisteet sopiviksi. Lisäksi tehtiin tutkimus tyytyväisyydestä luovutettuihin robottisoluihin.

Tutkimuksesta havaittiin suurimman osan vastaajista olevan pääosin tyytyväisiä solujen lopputulokseen.

Avainsanat kiertokankiverstas, robottisolu, läpimenoaika, Wärtsilä

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ABSTRACT

Author	Tiiu Tuohimäki
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This thesis was done for Wärtsilä's Connecting Rod Factory. The purpose of the thesis was to reduce the lead time of the W32 connecting rod lower part through the robot cell.

Connecting Rod Factory changed their manufacturing process to be mainly automatic during February 2016. The reason this thesis was needed was that the robot cell was unfinished so the lead time was unnecessarily long.

Methods used were research and practical work. The research was made regarding the delivered robot cells and satisfaction to them in general. The research showed that most of the participants were mainly satisfied with the cells. The goal with practical part was reached by going the programs thorough one by one and finishing or changing the ineffective movements and points.

The goal was reached, and lead time was reduced considerably.

Keywords Connecting Rod Factory, Wärtsilä, robot cell and lead time

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GLOSSARY

EPC	Short for engineering, procurement and construction.
W32	Wärtsilä 32 Engine.
Lower Part	Refers to the part in connecting rod that attaches piston module to the crankshaft.
W31	Wärtsilä 31 Engine.
W20	Wärtsilä 20 Engine.
UII	Unique Item Identifier.
SAP	Enterprise Resource Planning software program used by Wärtsilä.
R1	Short for Robot 1.
R2	Short for Robot 2.
R3	Short for Robot 3.
CMM	Coordinate Measuring Machine in Robot cell.
Lower Part pair	Refers to both parts of the lower part when they are unattached to each other.
Operator	Employee who works with the robots.
Conrod	Short for connecting rod.
FMS	Flexible Manufacturing System.
User Frame	Can be used for selecting origin position and changing it.
Tool Frame	Used of defining the tip of the tool.

CNT	When the robot approaches a target point, and CNT positioning path is specified, it does not stop the point but moves next to it making the movements smoother and faster.
OP	Short for Operator.
PR	Short for pinning robot.
WM	Short for Washing Machine.

1 INTRODUCTION

This thesis was done for Connecting Rod Factory at Wärtsilä. The manual manufacturing process of W32 connecting rod changed to an automatic process during February 2016. An automatic robot cell makes manufacturing more efficient and allows unmanned operation, so for example night shifts are no longer mandatory.

When the robot cell was compeleted, the programs were unfinished, supposebly because of rush. Most of the speeds were unnecessarily slow, and there was no consistency between the programs, for example the speeds used to execute practically same task varied considerably. The slow test speeds were probably left in the program, because fininshing the programs was not done properly.

The main aim of this thesis was to reduce the lead time of the W32/W34 connecting rod lower part through the robot cell. Connecting Rod consist of two parts, upper part and lower part (**Figure 1.**). The lower part was chosen because there is considerably more phases than in the upper part of the connecting rod and thus more room for improvement.

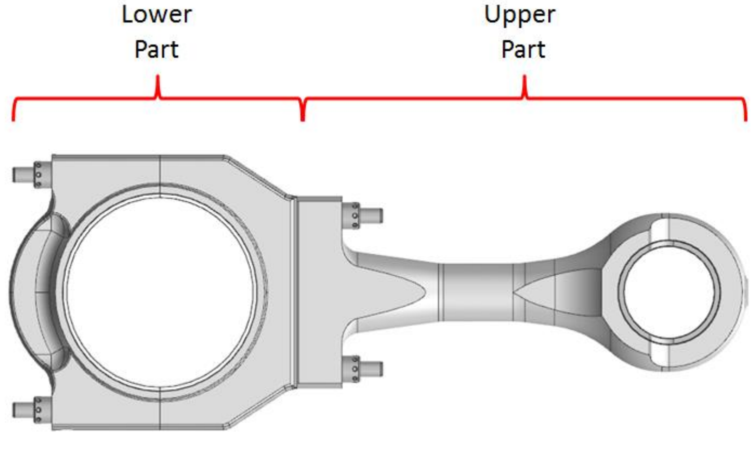

Figure 1. W32/W34 Connecting rod consists of two parts

This report starts with general information about robot cells and research declaration about satisfaction to the robot cells. After that there are introductions about Wärtsilä in general and then more specifically about the Connecting Rod Factory and the manufacturing process. When these topics are introduced, there will be a definition about the project itself, and then results. At the end of the thesis, there will be conclusions.

2 ROBOT CELLS IN GENERAL

Robot cells are becoming more common all the time around the world. Automation is the future, and robots evolve continuously. Automatization is important for companies, because it helps employees to understand new technologies better and makes their work easier and safer.

2.1 Basics

The robot cell includes a robot, controller and safety environment at minimum. Main purpose of the robot cell is move the parts from one place to another, and process the part towards finished product. Custom cells are built to answer the customers' needs, and they include parts such as grippers and part positioners /1/. Cells are often handed over in "turnkey"-principle, which means that everything is finished, and the company can just turn it on.

Some companies buy their robots and other parts separately, and build their own cell, which is a cheaper option if there already is an adequate knowledge about robots within the company. With this option parts can be bought where they are cheapest or best quality, depending on what company is looking for.

The robot cells can be customized in many ways. Many robot manufacturers provide smart accessories in their robots, like vision, optimized grippers for specific material and different safety solutions. One of the most important parts of the robot is the end-of-arm tooling. Most common tool for robot is grippers, which there are different types, for example: vacuum grippers, pneumatic grippers, hydraulic grippers, and servo-electric grippers /2/. Which gripper should be chosen depends entirely of the product which it is used for. Other common tools for the robots are clamps, vacuum cups, welding and painting tools, and finishing tools, such as metal brushes or files.

Most commonly automatized work assignments with robots are: Arc welding, assembly, coating, deburring, die casting, moulding, material handling, picking, palletizing, packaging, painting, transportation and warehousing /3/.

Few companies offer robots which can be guided by human by showing to the robot what to do. For example Fanuc collaborative robot CR-35iA. It can lift up to 35 kg, and can be simply pushed away by human hand. /4/ ABB also offers collaborative robot, YuMi. It has been named the best industrial robot of 2016 at the China International Robot Show /5/. YuMi can be shown what to do by grabbing it by the arm and moving the arm where it is wanted, point by point. It also has safety stop, it can be stopped by pushing it with the hand, so it does not need safety cages /6/.

Industrial robots are just one part of robot usage. Now days there are many areas that robots are irreplaceable, such as military, space exploration, and remote and minimally-invasive surgery, underwater exploration and investigating hazardous environments /7/.

2.2 Why Robots Are Used

Companies want more efficiency in production and less human errors. Robots work around the clock, even unmanned, and they reduce operating costs by not needing training, sick leaves or safety gear.

The highest priority for many companies is product quality, and it must be considered in every decision. With robots, the quality increases, because it will not suffer from tiredness or distraction. The robot repeats taught movements precisely, and that leads to more stable quality. Also, automation increases working conditions for employees as they can be removed from dusty, hazardous or repetitive work assignments, and instead be trained to program and operate the robots /8/.

Many work tasks require caution and carefulness, and when people executes these tasks, there are inevitably losses because of human errors. When the robot executes these tasks, losses reduce, because robots rarely make mistakes, and if they do, it is caused by the programming or for example a wrong tool. Also robots are commonly more precise than human workers, they can produce a greater quantity in the same time, and are capable of lifting heavy loads.

2.3 Research

To get real experiences about robot cells, a research questionnaire was sent to twenty people working with robot cells, of which ten people answered. Answers were given online, on a website called SurveyMonkey, anonymously. The questionnaire was written in Finnish. Questions and answers in its entirety are shown in the Appendices (Appendix 1).

2.3.1 Questions

Four questions were asked:

1. Which are the most important things about automatization and planning phase?
2. Are you mainly satisfied with the result of robot cells? Which things are you satisfied with and which could be done better?
3. Is there a plan for development or optimization?
4. In the entire process, which are the biggest challenges?

2.3.2 Results

Answers varied a lot, but there also were certain things which were found in many answers. Almost all the answers seemed professional and considered.

Detailed planning came up in most of the answers when asked “what is the most important thing about automatization”. Also, knowing customers’ needs and adjusting the cell accordingly was considered important. Additionally, understanding the process and keeping it as simple as possible, as well as right products for specific work were found to be needed.

Seven out of ten were satisfied with the results when the cell was handed over to the customer, but for example finishing, commissioning and optimization after the and-over were considered in need of improvement. It was also mentioned that keeping the schedule should be better. The remaining three people, who were not mainly satisfied thought that cells were done in rush, left incomplete or unfinished, and the testing phase was often too short.

Development and optimization after the cell has been handed over was mentioned to be important in more than three answers, but only two people answered straight that the optimization is part of the cell delivery. One answer mentioned that problems and challenges are really learned during the use, so problems should be discussed and fixed after the cell has been in use for some time.

Understanding the entire process came up in two answers, when questioned the major challenges in the entire process. Also, communication and mutual understanding between customer and deliverer were mentioned in four comments. Money and scheduling came up too.

2.3.3 Conclusions

In conclusion according to this research robot cells are mainly satisfying, but there still are important things to improve. Answers clearly showed that the cells are often handed over unfinished, and there are no plans to optimize the cell to answer the customers’ needs. That is why the optimization is a desirable opportunity for a thesis for both parties.

40 % of answerers wrote that the major challenge with the cells is that customer and deliverer do not understand each other correctly, when there can be confusion and misunderstandings what is expected of the cell. In addition there can be misunderstanding or different expectations inside the customers’ company, which can lead to confusion and frustration. When terms of contract has been filled, the cell can easily be left in that condition without finishing or optimizing.

3 WÄRTSILÄ OYJ

Wärtsilä is a global leader in complete lifecycle power solutions for marine and energy markets. In 2016 Wärtsilä's net sales totalled EUR 4801 million, order intake was EUR 4927 million and Wärtsilä had 18,011 employees. The company has operations in over 200 locations in more than 70 countries around the world. /9/

3.1 Organization

Wärtsilä is divided into three divisions, Marine Solutions, Energy Solutions and Services. /10/ Marine Solutions and Energy Solutions were previously known as Ship Power and Power Plants.

3.1.1 Marine Solutions

Marine Solutions offers Wärtsilä's customers with a wide array of products for "shorter route to bigger profits". Marine Solutions focuses on environmental products and services, with various technologies aimed to reduce the environmental footprint of their customers. Their emphasis is on lifecycle efficiency, attempting to minimize both the environmental impact of emissions and the volumes of waste. /11/

3.1.2 Energy Solutions

Energy Solutions offers power plants ranging from 10 to over 600 MW, operating on various fuels. Energy Solutions designs and builds power plants. Aside from designing and building the power plants, Energy Solutions is also a leading EPC contractor that provides their customers with financing, project development and project services.

Wärtsilä Energy Solutions offers Smart Power Generation based on internal combustion engines that run on any liquid or gaseous fuel. Smart Power Generation provides operational flexibility with fast-responding engines, energy efficiency due to the modular design of multiple cascading engines and fuel flexibility by being able run on any liquid or gaseous fuel, in addition to being able to switch from one fuel to another without stopping. /12/; /13/

3.1.3 Services

Wärtsilä Services offers support for its customers throughout the whole lifecycle of their products and installations. They aim to optimize the efficiency and performance of the customer's products for both Marine and Energy Solutions. Wärtsilä Services provides environmentally sound, high quality support for their customers anywhere in the world.

Services attempts to enhance its customer's business by offering lifecycle efficiency aimed to improve customer's profits by preventing the unexpected, optimizing the performance and improving the environmental efficiency of all Wärtsilä's installations. /10/; /14/

4 CONNECTING ROD FACTORY

The Connecting Rod Factory manufactures three different models of connecting rods, for W20, W31, W32 and W34 engines (**Figure 2.**). Connecting rods for W32 and W34 engines are the same model.

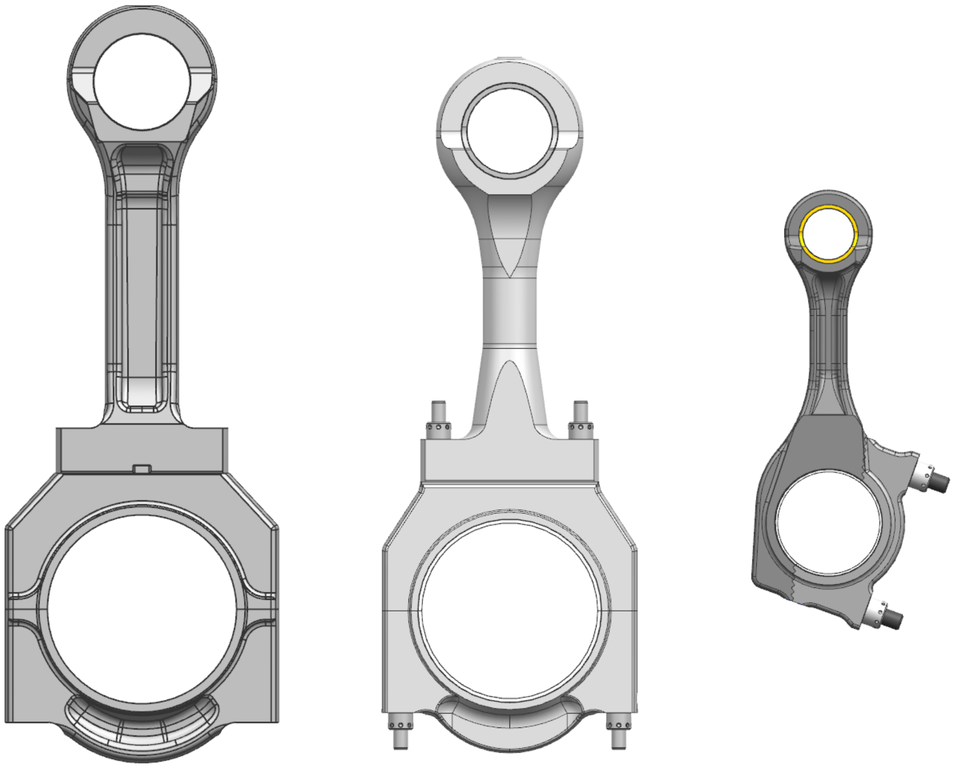

Figure 2. Connecting rod models, from left to right: W31, W32/W34, W20

4.1 Manufacturing of Connecting Rods

Manufacturing connecting rods is a complicated process and consists of multiple phases and operations. Connecting rod lower parts are delivered to the factory as forgings, and upper parts are premachined at the suppliers' factory. Rest of the work stages before attached to the crankshaft are done in the Conrod factory.

4.1.1 Traceability

Traceability project started at the Connecting Rod Factory in the summer of 2015. Completely new tracing system was taken in use during the project, before that tracing was done differently. In Traceability UII: s, in the form of Matrix Codes, are added into the Connecting Rod Factory's products to improve product quality management. The matrix codes in the products are read with code readers, which link them together in Wärtsilä's SAP database.

4.1.2 Machining

The connecting rod lower part machining consists of three phases: roughing phase 1, roughing phase 2 and fine machining. The machining of connecting rod upper part only takes one phase, so it is easier and faster to manufacture. There are two machining centres in the Connecting Rod Factory, Heller H10000 and Burkhardt-Weber BW120.

Before automatization the loading of the forgings into the fixture was done manually, and this was slow and heavy for workers. There were lots of manual measuring, which gave quite much room for human errors. Now CMM measures the pieces, two times during the process, and tolerance errors are tracked easier and more certainly.

4.1.3 Robot Cell

The Product Line for W32 Connecting Rods in the Connecting Rod Factory was changed to be mainly automatic in February 2016. The robot cell is part of the FMS-system, in which forgings are stored. Forgings are first send into the FMS-system through the input conveyor.

The cell contains five Fanuc robots and a Manual Station, which is still needed for hydraulic tensioning and dismantling of W32 Lower Parts. Additionally, there is a manual Quality Management-station, where damaged or tolerance overstepped pieces are taken for additional quality control. W20 and W31 connecting rods are still made with the old manual way.

All the robots in the cell are Fanuc-robots. R1 and R2 are model R2000iC/210F, R3 in model R-2000iB/165F, deburring robot is model M-710iC/50 and pinning robot is model LR Mate 200iD (**Figure 3**.).

Figure 3. From left to right; R-2000iC/210F, R-2000iB/165F, M-710iC/50 and LR Mate 200iD.

4.1.4 Assembly

The connecting rods are assembled into W20 Piston Modules, W32/W34 Piston Modules (**Figure 4.**), W32/W34 Conrod Modules and W31 Conrod Modules. The modules are sent forward to internal customers, where connecting rods are assembled into W20, W32, W34 and W31 engines.

Figure 4. Assembled W32 piston module and conrod module

5 FUNCTIONALITY OF THE ROBOT CELL

In this chapter functionality of the robot cell is explained. There are two main phases in the automatic process, when manufacturing lower parts, first roughing and then fine machining. After the automatic process is done, every part goes through the final deburring and visual check executed manually before moved into the assembly.

In figures 7, 8, 10 and 11 the work flow follows one particular piece through the process, although this is not necessarily the order in which the phases are normally executed.

5.1 Roughing

In the roughing phase the forging is machined nearly in its final measurements. Two pieces can be attached in the fixture (**Figure 5.**) at the same time, but depending on which place piece is attached, different process is done to the piece. Both processes has to be done to every piece.

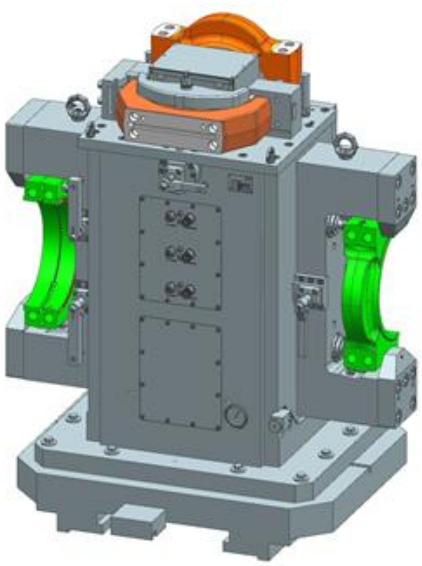

Figure 5. Roughing fixture

5.1.1 Robot 1

At first W32 connecting rod forgings are put into the system through the input conveyor. There the Unique Item Identifier, included in every part, is read so that every part can be traced through its lifecycle. UII is read with the matrix code reader, and linked automatically in SAP database.

When the roughing fixture arrives into the cell, the lower part pairs are deburred and pneumatically cleaned by R1. R1 unloads the phase 2 lower part pair and it is marked and moved into the washing machine (**Figure 6.**). Then R1 moves phase 1 lower part pair to phase 2. After that forgings are loaded into the phase 1, and fixture is sent into the FMS to be machined. After the washing the pieces are taken into the buffer R1/R2.

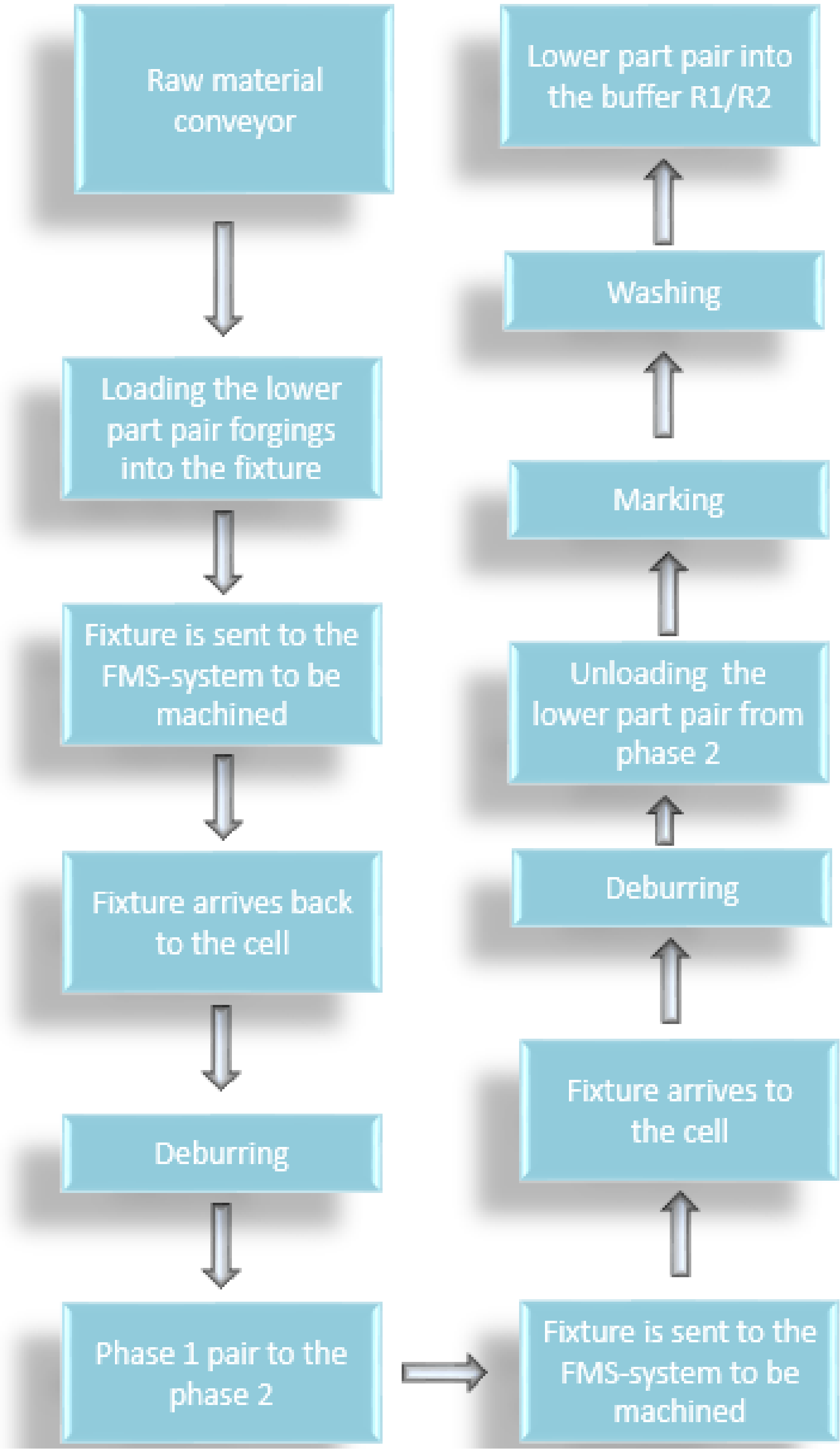

Figure 6. R1 tasks in the roughing phase when observing one particular piece

5.1.2 Robot 2

R2 picks the piece up from buffer R1/R2, and takes it to CMM to be measured. If deviations or tolerance crossings are found, R2 moves the lower part pair into the quality management-station, where it is inspected and to be approved or scrapped. If it is discovered that deviation is the result of, for example metal chips or dirt, the piece can be measured in the station and be sent back in to the system. If the deviation can be approved, the lower part pair is moved to the pinning robot. If there are no deviations, the part is moved straight to the pinning. At this stage, pins are put between the lower part pair. The reason why both halves in not pinned at the same time is that the critical measure of socket holes is best to measure when the piece is tensioned to one piece. If the pinning robot is occupied, the lower part is moved to the buffer R1 to wait.

After the pins are inserted, the lower part is moved to the manual station to hydraulic tensioning, done by operators. Hydraulic tensioning is done because bearing hole is machined in its final measurement in fine machining, and it has to be done when lower part is in one piece, because bearing hole has to be round when the connecting rod is attached to the crankshaft. When lower part is not tensioned together, it is slightly oval. If the manual station is occupied or there is no base plate, the part is moved into the buffer R2/R3 to wait for the placing of the base plate or that operators sent another part back to the cell. When the part is tensioned, the manual station turns automatically when R2 is ready for picking up the piece and takes it to the fine machining buffer (**Figure 7.**).

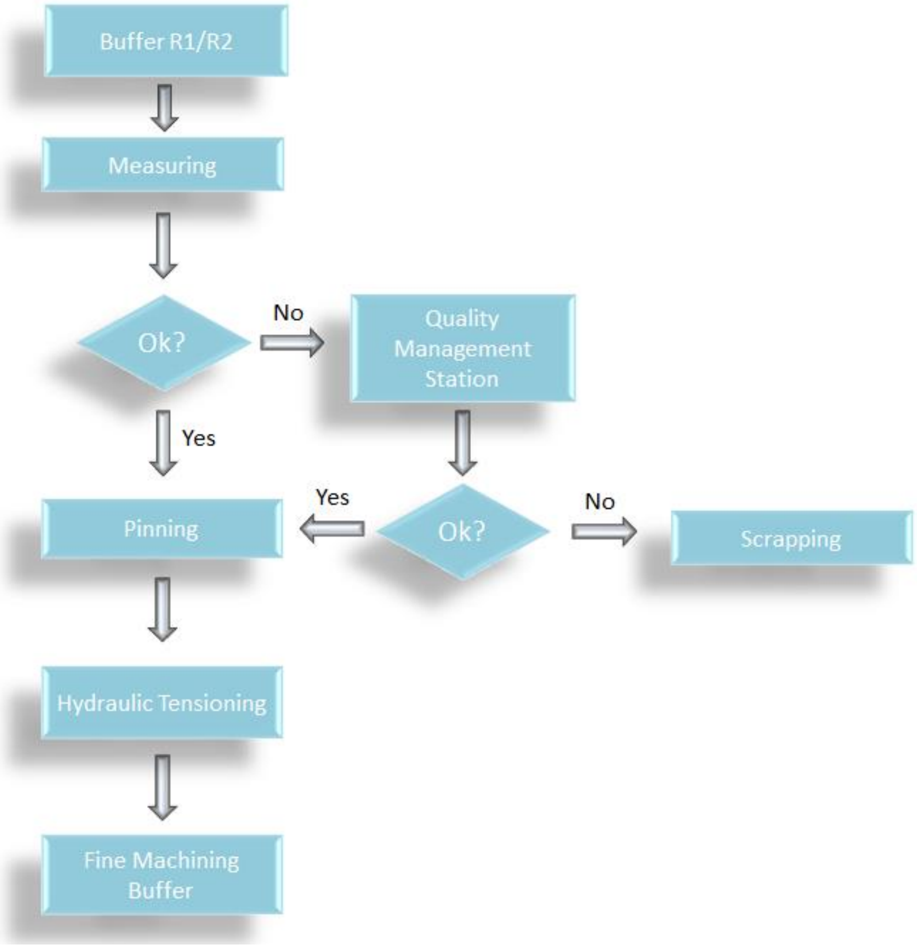

Figure 7. R2 tasks in the roughing phase when observing one particular piece

5.2 Fine Machining

When prepared for fine machining, the lower part pair is tensioned to one piece and the base plate is attached before loading pieces into the fixture. Two pieces can be fine machined at one time, as can be seen in the picture (**Figure 8.)**.

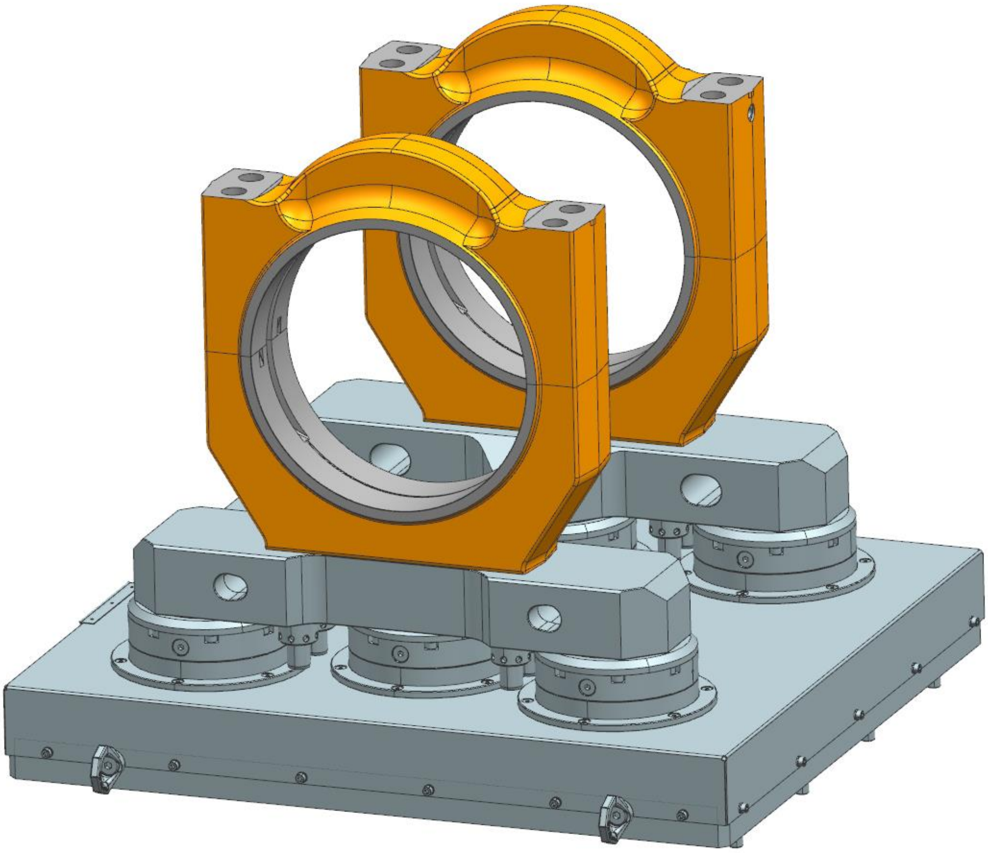

Figure 8. Fine machining fixture, bolts and nuts missing from the picture

Robot 1

At first, when the fine machining fixture arrives to the cell, part 1 is moved to the washing machine. When the washing is on, R1 loads a new part from the fine machining buffer to the fixture. Once washed, part 1 is moved from the washing machine to the fine machining buffer and part 2 is moved to the washing machine (**Figure 9**). Next, another roughed part is loaded onto the fixture and sent to the FMS-system to be machined. Lastly, part 2 is also moved from washing to the fine machining buffer.

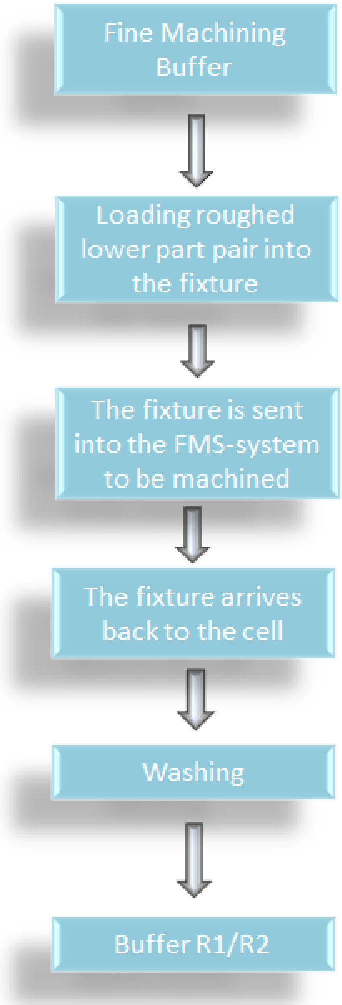

Figure 9. R1 tasks in the fine machining phase when observing one particular piece

5.2.1 Robot 2

The lower part is measured again, but this time at tensioned to one piece, so R1 moves it to the CMM. If deviations or tolerance crossings are found R2 moves the part into the quality management-station for inspection and to be approved or scrapped. If the deviation can be approved, the part is sent back to the cell to be moved by R2 to the manual station for dismantling by operators. If there are no deviations, the part is moved straight to the manual cell, where it is dismantled.

After the part is dismantled into two pieces, it is sent back to the cell and taken to the pinning robot. At this stage pins are inserted in the surface between the upper and lower part (**Figure 10.**).

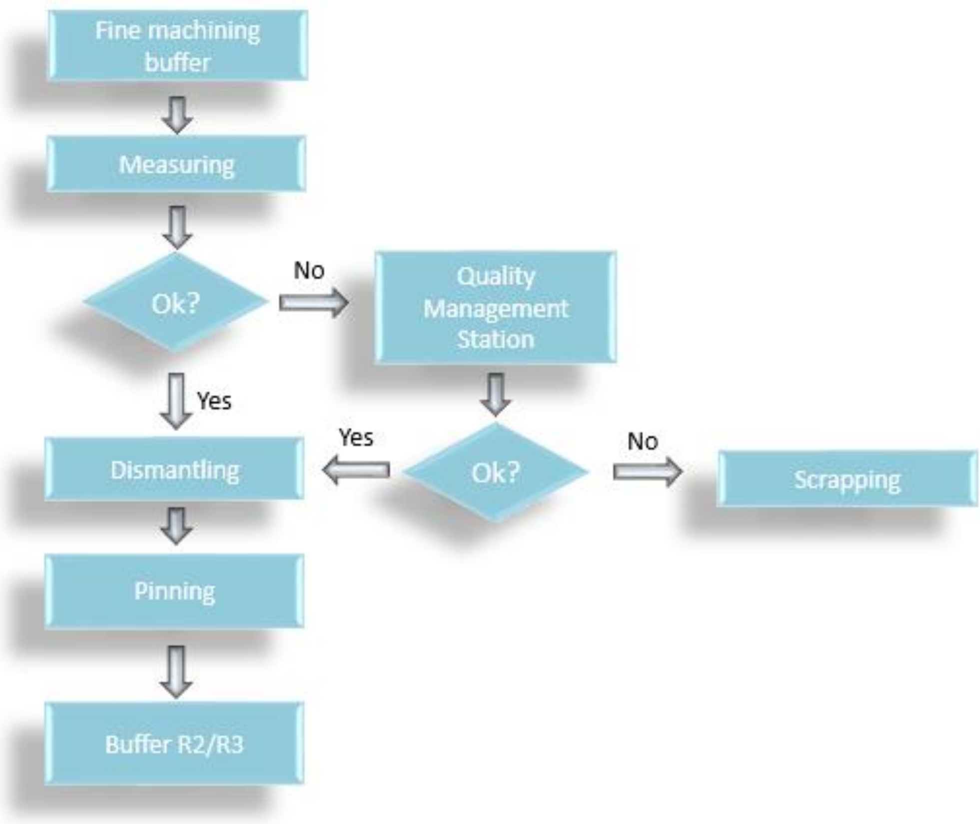

Figure 10. R2 tasks in the fine machining phase when observing one particular piece

5.2.2 Robot 3

After pinning, the lower part is transported to the buffer R2/R3, where R3 takes it to shot blasting via plugging. R3 has its' own buffer which use if some of the equipment is in use at the moment. Once shot blasted, plugs are removed and the lower part is transported to the deburring robot, which removes most of the excess burr. The last step in the robot cell for the lower part is when it is taken to the exit conveyor (**Figure 11.**).

From the exit conveyor the operator releases the lower part to assembly after manual deburring and visual check.

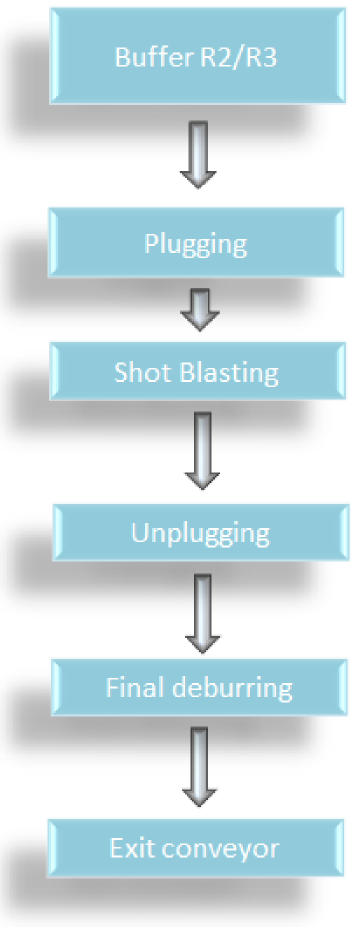

Figure 11. R3 tasks in the fine machining phase when observing one particular piece

6 DEVELOPMENT TARGETS

Development targets were quite clear from the beginning, but there were a few things that had an impact on prioritizing.

6.1 Project Definition

The project was prioritized based on which phases took the longest time and slowed the cell down the most. After going through the process, it was decided that R1 and R2 were the most relevant. Originally the plan was to go through all three handling robots but because of the time restraints R3 was left last to see if there is time to go through it.

In the robot cell there are several phases when the robot needs to turn the piece over in order to take it safely to the next destination, so there are two possible gripping places for robot (**Figure 12.**). It is done by putting the piece down as the way it currently is on the holder designed only for this purpose, and gripping the piece from the other aide. It was in the original plan to consider if all turns are necessary, and it was started, but in the end there were no time to finish it.

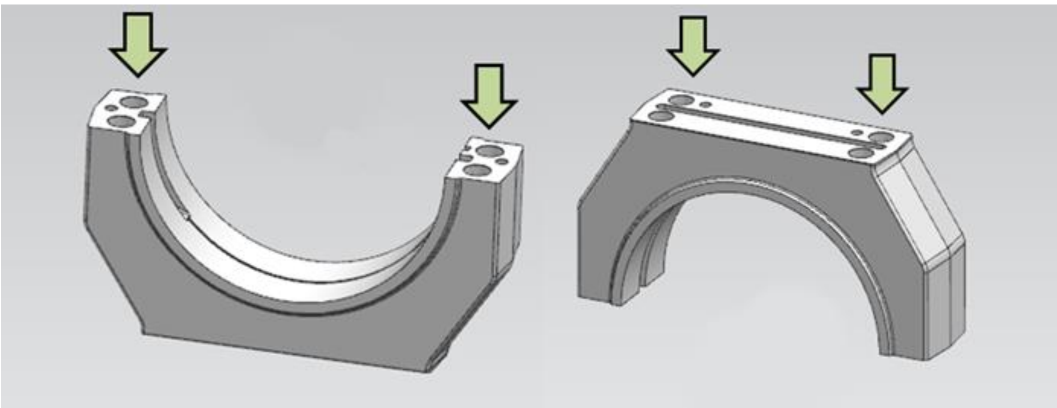

Figure 12. Possible gripping places

6.2 Project Plan

It was decided to start with fine machining phases, because it felt easier to understand as a process at first. In the project plan there were originally eight four hour work days, for each phase: fine machining phases R1, fine machining phases R2, roughing phases R1 and finally roughing phases R2. Also there were four last weeks reserved for writing.

The plan changed a few times, because the first few hours were spent studying the controller, so it took nine work days to finish the R1 fine machining phases. The problem was solved by taking one week of writing off and adding roughing phases R2 instead. At the end though it was noticed that the project was week ahead, so after all it was fine.

The original and updated time schedule of the project plan can be found in Appendices 2 and 3.

7 CHANGES MADE

There were a lot of changes made, especially in the movement speeds and adding or removing motion points. Also, the logic of hydraulic sequences of the machining fixtures were considered and changed. The general guide for robot cell optimization is in the Appendix 4. This project was done as described in it.

7.1 Process Mapping and Execution Planning

Before real changes were made, the program structure had to be considered and examined. At first backup-programs were taken from the robot, and an Excel file about structure was prepared to make clear which program is called in which program. This was important also to see the entire process more clearly, and to know in which program to return when changes are made.

Before really changing anything the test fixture was chosen, so it could be taken out of the system before it is tested properly if there is no time to do the testing immediately. After one fixture was proven to work, changes were copied into other fixture programs. There are also fixture-specific programs, and general programs, so it was important to make sure the type of the program before changing anything.

7.2 Roughing Phases

Changes made for robot R1 were complicated, because R1 is the robot that takes components away from the machining fixture and loads new forgings into it. There are holders that either keeps the piece fastened during machining, and pushers, which makes sure that the piece is into its right place when the holders are closed. There were several steps with hydraulics involved, which took a lot of time as the holders closed every time a component was taken away from the fixture and opened again when a new forging was taken to its place (**Figure 13.**). Closing holders every time was considered not necessary until just before the fixture is ready to send into the FMS-system to be machined. The problem was solved by adding an if-sentence, which made hydraulics close only when the fixture is ready to be machined (**Figure 14.**).

```
!================================ ;
! Fastems ALD ;
!================================ ;
! Palettiaseman ajo hissin ;
! paatyyn ;
!================================ ;
 ;
IF DI[18: Liitin alhaalla]=ON AND DI[20: Liitin auki]=ON,JMP LBL[10] ;
 ;
Irtikytke hydrauliikka    ;
 ;
LBL[10: Hydrauliikka ok] ;
 ;
! Pyoritys kotiasemaan ;
Aseman pyoritys(0) ;
 ;
! Ajo paatyyn ;
Aseman ajoliike((-2172.36)) ;
/POS
```

Figure 13. Program before project

```
!================================ ;
! Fastems ALD ;
!================================ ;
! Palettiaseman ajo hissin ;
! paatyyn ;
!================================ ;
 ;
SELECT R[10: Palettimuisti]=8,JMP LBL[1] ;
       =9,JMP LBL[1] ;
       =17,JMP LBL[1] ;
       =18,JMP LBL[1] ;
       ELSE,JMP LBL[2] ;
 ;
LBL[1: Hienoajot] ;
 ;
Sulje hydraulikiinnitin(4) ;
 ;
LBL[2: Muut] ;
 ;
 ;
 ;
SELECT R[10: Palettimuisti]=5,JMP LBL[3] ;
       =6,JMP LBL[3] ;
       =15,JMP LBL[3] ;
       =16,JMP LBL[3] ;
       ELSE,JMP LBL[4] ;
 ;
LBL[3: Rouhinnat] ;
 ;
IF DO[63: Rouh kiinni]=ON,JMP LBL[4] ;
 ;
Sulje hydraulikiinnitin(1) ;
Sulje hydraulikiinnitin(2) ;
Sulje hydraulikiinnitin(3) ;
Avaa hydraulikiinnitin(2) ;
Avaa hydraulikiinnitin(1) ;
Sulje hydraulikiinnitin(3) ;
 ;|
LBL[4: Muut] ;
 ;
R[10: Palettimuisti]=0    ;
DO[63: Rouh kiinni]=OFF ;
 ;
IF DI[18: Liitin alhaalla]=ON AND DI[20: Liitin auki]=ON,JMP LBL[10] ;
 ;
Irtikytke hydrauliikka    ;
 ;
LBL[10: Hydrauliikka ok] ;
 ;
! Pyoritys kotiasemaan ;
Aseman pyoritys(0) ;
 ;
! Ajo paatyyn ;
Aseman ajoliike((-2172.36)) ;
/POS
/END
```

Figure 14. Program after changes

At first when fixture arrived to the cell, the program was run line by line to make sure that every phase was run correctly. When there were actual movement of the robot, pause was added to the program after movement points, commonly when robot returned in its home point. Then the movements and speeds were watched through, and analysed if the motion points were all necessary and in sensible places.

There were few movement points that were unnecessary, and were first remarked (the program skips remarked lines) and then deleted if after testing it was clear that the point were not needed. Several of the movement points when approaching the piece were left too far of the piece, and robot had to make long, slow movement into the end point. These situations were solved by moving the motion point before end point closer to the piece, or adding a motion point in between, so robot could move faster into the last motion point, and slow movement into the end point got shorter.

There were no programs in which anything was not changed, almost every movement in every program needed optimization. In some cases speed was changed from 40 % up to 100 %, because gripper was empty and there was none crashing risk into anything.

Linear moves were used too often that could as well be joint moves, so those were changed. The speeds used in the joint moves were originally 40-60 % without the piece aboard, and with piece 20-30 %. Almost all of the movements with the piece aboard were changed to 40 %, because after testing it seemed suitable. Although there were few cases in which speed with the piece aboard was 50 %, and those were reduced to 40 %, because of the consistency and safety reasons. Without the piece it was decided case-by-case, but around 70-100 %.

Suitable speeds for every movement phase were found early on, and written down. Those speeds were used in all similar movements for keeping the program consistent safe.

The CNTs values were originally left too small, and there were used Fine movements in places that do not require that. When changes were made, the fine movements were only used with the two last movements when leaving or picking up the piece. All of the other movements there were CNT added, for example some moves CNT value was originally 20, and it was changed up to 100, because there was no risk of hitting anything.

7.3 Fine Machining Phases

Fine machining phases were changed in quite in the same way than the roughing phases. Hydraulic sequences were changed in the same way, and movement points, speeds and CNTs were improved.

7.4 Testing Methods

Testing was done after every change, one phase parts at the time, for example transportation from the home point into the washing machine. At first the changed motion points were tested using the Step-function (the program is run step by step, one row at a time manually). When the motion points were found to be working, speeds and CNTs were tested by adding the speed slightly with every run through starting with just 20 % speed until 100 % speed.

7.5 Problems during the Work

There were some problems with the user frame and tool frame when adding a new point or sometimes even when changing the place of the old point. In some of the programs there was not automatic specification about the used user frame and tool frame, so when the motion points were gotten through after changes, the user frame or tool frame was wrong and the motion was different than it was supposed to be. After the first time this happened it was checked every time that a new point was created.

The problem with the user frames and tool frames occurred because they were not defined at the beginning of the program, and there was a different user frame active than what was defined to the point. The robot still can do the movements correctly if the program is run forward, but when the program is run backwards, there might be unexpected problems.

One accident happened with hydraulic changes, because there was a typing error in the program. That led to the fixture being open while machined, but in that case too it was noticed in time and nothing serious happened.

7.6 Quality Improvements

Reducing the lead time was the main goal while doing this project, but quality has gotten better as well. During the project it was noticed that there were sometimes metal chips on the surfaces that are very critical, because the chips were blown around the cell when the piece was pneumatically cleaned. The problem was solved with adding a box with brushes in which the piece is pneumatically cleaned, so the metal chips are staying inside the box (**Figure 15.**).

Figure 15. The box in which the pieces are cleaned

Before the box was added, from 1.5.2016 to 31.3.2017, there were 17 quality notifications concerning this case, when after adding the box there has been only 2.

Cleaning the piece is highly important to do properly when needed, so there is not much room for speeding up the process, because quality might suffer from it. At first, fixture was cleaned after fine machining when the piece was already picked up by the robot 1. That was the faster way, but the robot does not get so close to the fixture. During this project cleaning was changed such as zero point elements are pneumatically cleaned after the piece is transported into the washing machine pallet, so the robot can get nearer to the fixture. From 1.5.2016 to 23.2.2017 there were 22 quality notifications regarding this case, when after there were none. This was highly successful.

It was also noticed that when the piece comes out of the washing machine, there was washing liquid left in the holes and grooves. The result was that liquid splashed around the cell when the robot started to transfer it to the next place, which created dangerous situations when entering the cell, and also fluid ended up on measuring pallet. Originally the robot tilted a piece above of a box which collected liquids, but still there were some left in the piece. During this project a turning around was added, so the robot turns the pieces all the way upside down, so all the liquids can get out of the piece.

8 RESULTS

The goal, which was to reduce the lead time, was reached. This chapter shows improvement percentages at table form, both roughing and fine machining separately. There are also conclusion table, which can be seen a bigger picture about changes.

8.1 Improved Phase Times: Roughing

The roughing phase times were improved at the minimum of 2,5 %, and the maximum of 60 %. The total time fixture is in the cell improved by 29,10 %, as can be seen from table 2. Some phases could not be improved, such as hydraulic tensioning, because it is done manually. Also CMM and washing machine programs did not need improving, because it could easily affect quality badly. CMM however was changed during this project, but it did not include in this project, so differences in those phases will not be counted in improvement times.

All the results of roughing phase times are in table 1 and 2 below. Grey rows are phases that could not be changed with R1 or R2 programs.

Loading time in the conclusion table 2 is the time from that moment that fixture arrives to the cell to that moment when it is sent back in to the FMS-system to be machined.

Table 1. Results of the roughing phases

Executor	Task	Improved Time (%)
	Roughing fixture arrives to the cell	0 %
R1	Deburring	0 %
R1	Unloading, Phase 2 +Marking +Transportation to the Washing Machine	-27,8 %
WM	Washing	0,0 %
R1	Transportation from phase 1 to phase 2 +hydraulics	-38,3 %
R1	Loading a forging pair into the fixture	-60,0 %
	Fixture is sent to FMS-system to be machined	0,0 %
R1	Transportation of roughed lower part pair from washing machine to buffer R1/R2	-29,7 %
R2	Transportation of roughed lower part pair from buffer to the measuring machine	-31,9 %
CMM	Measuring +Movement of the conveyor + Surface Roughness Measurement added	0,0 %
R2	Transportation of lower part pair from measuring machine to the pinning robot	-23,9 %
PR	Pinning of middle part	0,0 %
R2	Transportation of lower part pair to hydraulic tension	-21,4 %
OP	Hydraulic tension +Movement of the station	0,0 %
R2	Transportation of lower part pair from manual station to fine machining buffer	-2,5 %
	Total	-12,5 %

Table 2. Conclusion about roughing phase times

Task	Improved Time (%)
Roughing, robot changes total	-33,2 %
Roughing, loading time	-29,10 %
Roughing, complete process	-12,5 %

8.2 Improved Phase Times: Fine Machining

The fine machining phase times were improved by the minimum of 20,6 %, and the maximum of 60 %. The time that the fixture is in the cell improved by 40 %. As in roughing in fine machining all times could not be improved, either, such as dismantling which is done manually. The pinning did not need improving, either because the program was already finished shortly after the cell was handed over. The washing machine uses the same program than roughing, so it did not need improvement.

CMM was changed during this project, but it did not include in this project, so differences in those phases will not be counted in improvement times.

All the results of fine machining phase times are in table 3 and 4 below. Grey rows are phases that could not be changed with R1 or R2 programs.

Loading time in the conclusion table 4 is the time from that moment that fixture arrives to the cell to that moment when it is sent back in to the FMS-system to be machined.

Table 3. Results of the fine machining phases

Executor	Task	Improved time (%)
	Fine machining fixture arrives to the cell	0 %
R1	Transportation of lower part 1 from the fix-ture to the WM	-41,1 %
WM	Washing	0 %
R1	Loading of lower part pair from fine machin-ing buffer to the fixture	-55,6 %
R1	Transportation of lower part 1 from WM to fine machining buffer	-28,3 %
R1	Transportation of lower part 2 from the fix-ture to the WM	-60,0 %
WM	Washing	0,0 %
R1	Loading of lower part pair from fine machin-ing buffer to the fixture	-55,6 %
	The fixture is sent to the FMS-system to be machined	0,0 %
R1	Transportation of lower part 2 from the WM to fine machining buffer	-25,8 %
R2	Transportation of the lower part from fine machining buffer to CMM	-29,8 %
CMM	Measuring (+ movement of the conveyor)	0,0 %
R2	Transportation of the lower part from CMM to the manual station	-48,6 %
OP	Dismantling	0,0 %
R2	Transportation of the lower part from manual station to the PR	-20,6 %
PR	Pinning	0,0 %
R2	Transportation of the lower part from pinning robot to the R2/R3 buffer	-21,8 %
	Total	-11,0 %

Table 4. Conclusion about fine machining phase times

Task	Improved time (%)
Fine machining, robot changes total	-35,0 %
Fine machihing, loading time	-40,0 %
Fine machining, complete process	-11,0 %

9 CONCLUSIONS

The project was successful, and the results were what we wished for. The schedule changed only a few times, and everything planned to be done was done. Communication worked well both ways, and it was clear how to proceed all the time.

There were some unpredictable challenges, but they were noticed and solved before anything serious occurred. The Connecting Rod Factory employees were very helpful and understood the importance of this project, and noticed the difference.

9.1 Further Development

During this project a few more things were noticed that could be improved. When the piece goes into the pinning, the pinned part is already at the robot, when the other half is pneumatically cleaned and taken to its place into the pinning area. If the pinning would be done at the same time when the other part is cleaned, it would save a lot of time.

It was also noticed that turning the part takes a long time because it has to be done so often. If there were buffers, where the robot could grip the piece on either side, at least few turn overs could be avoided.

Robot 3 remains unfinished as for the lower parts and upper parts. R1 and R2 as for the upper parts are unfinished, and the concluded results from this project it would be profitable to optimize those programs too.

9.2 Self-Evaluation

This thesis was just right for me, and I enjoyed doing it. It was also very thoughtful in many ways. The project taught me the importance of finishing properly the work in the future. I learned also important skills needed to work with robots, such as patience, carefulness and thinking before pressing anything.

Planning went well, and we held meetings to see where the project was going and what is still missing from it.

One thing that should have been done better was my personal notes while executing the project. There were a few pages that did not make sense while I started writing the report after few weeks. I also forgot to take two original phase times, so we had to take those times after there already were some improvement made.

The project plan could have also been better and more detailed. It also should have been updated properly after every change. Now it was updated about once a month.

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APPENDIX 1

Tutkimustulokset:

1. Mitkä asiat koet tärkeimmiksi automatisoinnissa ja sitä suunniteltaessa?
    - Tarkoituksenmukaisen laitteiston suunnittelu ja toteutus. Välillä järjestelmistä tehdään turhan monimutkaisia ja monipuolisia ja toisaalta välillä koitetaan lähteä automatisoimaan hankalaakin kohdetta liian kevyillä suunnitelmilla. Tärkeintä mielestäni automatisoinnissa on ymmärtää eri laitteiden hyvät ja huonot ominaisuudet. On esimerkiksi erotettava mitä asioita kannattaa tehdä robotin ohjauksella ja mitä järjestelmässä olevalla PLC:llä. Lähtötietojen laatua ei myöskään pidä unohtaa. Kaikki suunnittelu kuitenkin tehdään lähtötietojen perusteella.
    - Todellinen takaisinmaksu laskelma. Kyvykäs toimittaja valinta.
    - Kannattavuus. Ei automatisoida pelkästään siksi, että jokin prosessi voidaan automatisoida, vaan siksi, että se on kannattavaa. Tämä on lähes poikkeuksetta ensimmäinen asia mikä lasketaan ja tutkitaan automatisointia suunniteltaessa
    - Automatisoitavan prosessin ymmärtäminen, jotta kehitetään oikeaa kohdetta; joustavuus ja muutosten huomioon ottaminen; kustannustietoisuus elinkaaren yli, eli ei pelkästään laitteiden hankintahinta, vaikka sekin on tärkeätä; asiakkaan haastaminen, eli pengotaan kaikki tarpeelliset asiat ja todelliset vaatimukset esiin eikä tyydytä geneeriseen "vain paras laatu kelpaa"-bullshittiin.
    - Hyvä suunnittelu ja riittävä pelkistäminen. Jos yhdellä solulla vastaa 20 eri tehtävään ja tekee niitä 8 eri tarttujalla 5 eri linjalle niin todennäköisyys projektin mennä pitkäksi on >95%.
    - Konedirektiivien mukainen suunnitelma ja aikataulussa pysyminen. Vaihtoehtoisten menetelmien miettiminen.
    - Automatisointiin soveltuvat tuotteet ja tuotantomenetelmät.
    - Idea kuinka automatisoidaan ja sen toteutus.
    - Se, että automaatiolla saavutetaan jotain oikeaa hyötyä edeltävään tilanteeseen verrattuna. Automaatiossa itsessään tärkeimpänä ominaisuutena pidän toimintavarmuutta. Suunnittelua koskien vanha sananlasku pitää enemmän kuin hyvin paikkansa, hyvin suunniteltu on puoliksi tehty. Suunnittelun puutteet aiheuttavat usein suuria haasteita toteutusvaiheessa.
    - Käsiteltävien kappaleiden tulee olla tasalaatuisia ja automaatio tulisi suunnitella siten, että se tarvitsee mahdollisimman vähän ihmisen vaikutusta, esim. kappaleiden syöttö automaattiin tulee olla nopeaa ja yksinkertaista, että senkin voi jatkossa automatisoida. Automaatti tulisi aina suunnitella laajennettavaksi.

2. Oletko keskimäärin tyytyväinen robottisolujen lopputulokseen? Mihin asioihin olet tyytyväinen, ja mihin usein jää parannettavaa?
    - Yleisesti ottaen olen tyytyväinen lopputulokseen. Parannettavaa jää, mikäli lähtötiedot ja toiminta-ajatus muuttuu kesken automatisointiprojektin.
    - kyllä, Innovatiiviset ratkaisut, miehittämätön ajoaika.
    - Olen keskimäärin tyytyväinen robottisolujen lopputulokseen. Toistaiseksi projektit ovat onnistuneet pääpiirteittäin suunnitellusti. Automaattisolun käyttöönoton jälkeinen tuki tuotannolle/operaattoreille sekä käytettävyystason ylläpito ja nosto ovat asioita joissa on ollut parannettavaa.
    - Keskimäärin joo, mutta usein parannettavaa jää siihen, että ratkaisut ovat jotenkin kökköjä eikä niitä tule laitettua kuntoon vaan tuotantoon jää puolivillaisia virityksiä; aikataulutus on myös usein hankalaa ja toisinaan pettymyksen aihe viivästyksineeen.
    - Fifty-Sixty. Joskus tulee tehtyä tai nähtyä loistavia suorituksia, joskus voi tyytyväinen siihen, että saa älyttömän kohteen joko luovutettua (ei välttämättä hyväksi) tai tehtyä (siis tyydyttävästi/hyvin).
    - Teknisesti OK Parannettavaa on käyttöönotossa
    - Suorituskyky yleensä ok, jos suunnittelu on mennyt ok. Joustavuus jatkossa on usein hankalaa.
    - Kyllä. Suoritustason parannukset esim. puolen vuoden käyttökokemusten jälkeen jäävät lähes aina tekemättä/ostamatta.
    - En ole. Oman kokemuksen perusteella robottisolut jäävät todellisuudessa kauas siitä haavekuvasta, jollainen projektien alkuvaiheessa toimituksesta maalataan. Solujen ratkaisuista paistaa todella usein kiire ja keskeneräisyys läpi. (esim. mahdolliset fiksut ratkaisut korvataan yksinkertaisilla "mistä aita on matalin" -tyyppisillä ratkaisuilla, robottien liikkeet ovat hitaita ja epäjohdonmukaisia) Voisi ehkä sanoa, että usein robottisolutoimitus on kuin luuranko, johon joudutaan sitten jälkikäteen lisäämään myös lihat luiden ympärille.
    - Kohdassa 1 mainitseminen asioihin jää usein parannettavaa ja automaattilinjat ovat usein protoja joissa ohjelmiston testaaminen jää usein turhan lyhyeksi.

3. Onko jatkokehitykselle ja optimoinnille suunnitelmia?
    - Jatkokehitystä ja optimointia kannattaisi mielestäni aina tehdä automatisoinnin jälkeen. Yleensä automatisoinnin jälkeen prosessista huomataan aina kehitettävää, joten parhaan hyödyn saamiseksi optimointi on tärkeää.
    - Kyllä.
    - Jatkokehityksille ja optimoinnille on monessa projektissa suunnitelmia/tarvetta. Usein optimoinnin tarve kasvaa automaatin valmistusvolyymin ja automatisoidun prosessin kompleksisuuden mukaan. Jos automatisointi on toteutettu sellaiseen prosessin vaiheeseen, mikä ei ole koko prosessin kannalta ns. pullonkaula, ei optimoinnille useinkaan ole tarvetta.
    - Jatkokehitystä tehdään osana tuotantoa, koska solut on suunniteltu alusta saakka itse omaan tuotantoon. Jos solu ostetaan valmiina toimittajalta, kehittäminen jää kenties helpommin tekemättä.
    - Yksittäisen kohteen automatisointi on tekijäfirman kannalta monesti huono bisnes, nautittavinta ja kannattavinta on tehdä räätälöitävä ratkaisu joka sopivan pienin muutoksin on myytävissä toisellekin tarvitsijalle, tai toiselle linjalle, kunnon katteella.
    - Ei ole.
    - Harvoin.
    - Ei juurikaan mitään suunnitelmallista. Voitaisiin esim. aloittaa uusi projekti jonkin uuden robottisolun kohdalla vaikka puoli vuotta käyttöönoton jälkeen, jossa käytäisiin käytössä esiin tulleita ongelmia ja haasteita läpi. Kuitenkin vasta solun päivittäisessä käytössä opitaan kunnolla ne oikeat haasteiden paikat ja pullonkaulat.
    - Optimointia tehdään usein.

4. Mitkä ovat suurimmat haasteet koko prosessissa?
    - Oikeiden ja merkityksellisten lähtötietojen välittäminen loppuasiakkaalta robottijärjestelmän toimittajalle.
    - Kokonaisuuden ymmärtäminen ei liian isoa tai pientä järjestelmää kerralla.
    - Automatisointiprojektin haasteet riippuvat paljon siitä, että minkä tyyppisestä toteutuksesta on kyse ja kuinka monimutkainen prosessi on tarkoitus automatisoida. Usein kompleksinen automatisointiprojekti vaatii muutoksia olemassa olevaan valmistusprosessiin ja jopa prosessissa/tuotteessa käytettäviin komponentteihin. Tämä

vaatii tarkkaa projektinhallintaa ja aikataulutusta eri funktioiden välillä (esim. strateginen osto ja tuotekehitys) vaadittujen muutosten läpiviennissä.

- Kokonaisuuden ymmärtäminen ja oikean automaatioasteen päättäminen, eli ei yritetä automatisoida kaikkea, mutta kuitenkin tarpeeksi
- Viestintä!! 2. Kunnollinen suunnittelu ja riittävä lähtötietojen kaivaminen niiltä jotka eivät osaa tai ymmärrä tarvittavia rajoitteita ja ehtoja ja kaikkia tarpeita kertoa 3. Aika x Budjetti x Tekn. tavoite x Resurssit = "Kulut" (kattoiko saatu liikevaihto nuo "kulut" ja mitä jäi voitoksi, niin rahallisesti kuin myös muiden em. tekijöiden taloudellisen käytön kannalta, eli tuliko aikaa, investointibudjettia, ja parhaita aivoja käytettyä järkevästi)
- Aikataulussa pysyminen.
- Määritellä tarpeet ja vaadittava suorituskyky toteutukselle. Saada toimittajalta tarjous oikeanlaisesta solusta.
- Tietojenkäsittely ja -hallinta.
- Kommunikaatio toimittajan ja asiakkaan välillä ja kustannusten hallinta. Joskus on ollut haasteita siinä, että löytyy yhteinen sävel asiakkaan ja toimittajan välillä. Eli että asiakas osaa kertoa toimittajalle mitä halutaan, ja että toimittaja osaa kertoa minkälaista ratkaisua tarjotaan, ja että nämä molemmat asiat ymmärretään molempien osapuolten osalta samalla lailla. Kustannusten puolesta joudutaan usein toimimaan tiukoissa raameissa, ja tämä aiheuttaa haasteita siinä, ettei välttämättä aina riitä rahaa kaikkeen siihen mitä projektien alkupuolella on kuviteltu toimitukseen sisältyvän. Tällöin myös robottisolun toiminta jää helposti vajavaiseksi kuviteltuun tasoon verrattuna.
- Aikataulu ja käytettävissä oleva raha.

APPENDIX 2

W32 Lower Part Robot Cell Optimization, Project Plan.

Done	Planne d

Change	40	41	42	47	48	49	50	51	3	4	5	8	9	10	11	12	13	14	15	16
Fine machining phases R1																				
Fine machining phases R1																				
Fine machining phases R1																				
Fine machining phases R1																				
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Roughing phases R2																				
Roughing phases R2																				
Roughing phases R2																				
Finishing and writing																				
Finishing and writing																				
Finishing and writing																				

APPENDIX 3

W32 Lower Part Robot Cell Optimization, Project Plan.

Done	Planned

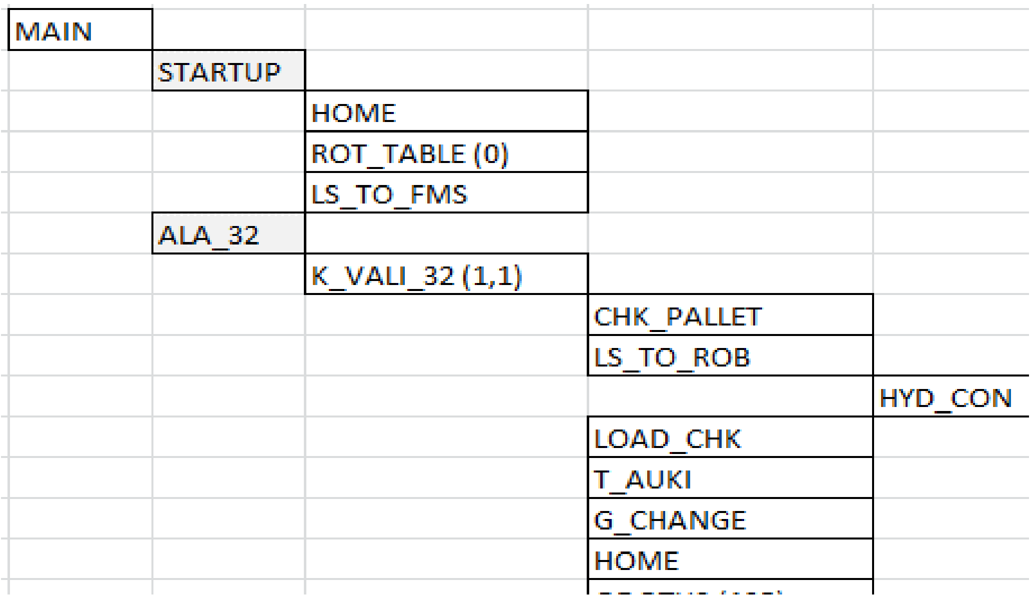
Change	40	41	42	47	48	49	50	51	3	4	5	8	9	10	11	12	13	14	15	16
Points added, moving speed and CNT																				
Same as above																				
Transportation to washing machine OK.																				
Pick up -points 1-4 changed.																				
Pick up -points 1-4 changed.																				
Point 1 pick up speed changed. (Crash into the part)																				
Pick up and delivery point 1 OK.																				
Loading the fixture and moves OK.																				
Pick up from the washing machine OK.																				
Delivery points OK.																				
Speeds changed, R1 safe point moved further away.																				
Hydraulics on/off changed. (IF-statement added)																				
Points and speeds OK.																				
Fininshing R1 Fine- machining.																				
FM R2, Pick up -points and speeds OK																				
Transportation to washing machine OK.																				
A2 transportation Ok, Base pick up OK.																				
Pick up from manual station OK.																				
Rest of the manual station OK.																				

Phase 2, lower part OK.																				
Marking and delivery to washing (Lower part) OK.																				
Transportations to marking and washing machine OK.																				
Cleaning of the gripper, Loading and forging OK.																				
Roughing phases R1																				
Roughing phases R1																				
Roughing phases R2																				
Roughing phases R2																				
Roughing phases R2																				
Roughing phases R2																				
Roughing phases R2																				
Roughing phases R2																				
Roughing phases R2																				
Roughing phases R2																				
Finishing and writing																				
Finishing and writing																				
Finishing and writing																				

APPENDIX 4

General Guide to Robot Cell Optimization

1. At first go through the programs, and build up the structure of the process, for example on an Excel. Make sure you understand the entire process before making any changes.



2. Take backup files from the robot on to the flash drive, so you have them if something goes wrong.

3. As you start to go through the programs with the robot controller, remember to check you have step-function on. Go line by line as long as you find lines where robot moves.

4. Add pause-command before gripper opens or closes. Look through the movements and speeds first without step-function. If ok, continue going with step-mode, until you find movements that are not ok.

5. Go backwards in to the start point, and make the changes you are going to make.

6. If you have made changes to the points, such as added, removed or moved the point, go points through with step. Remember to check that the user tool and the tool frame are what they are supposed to be.

7. Go again backwards in to the star point, and turn off the step-function. Start with slow speed, for example 20 %, and look through. If something looks suspicious, release shift and check that everything is ok, and then go again with slower speed.

8. Repeat previous step with adding speed 20 % at the time until you reach to 100 %.

9. **Remember to take the pause-command off before continuing!**

10. When robot is turned back to automatic drive, look through the changed part at least a few times to make sure that everything works like it is supposed to.

11. During work when you find a suitable speed for some specific situation, for example maximum speed when piece is aboard, write it down and use that speed in every similar situations.